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APPLICATION OF THE SMALL BODY PRESSURE TRANSDUCER

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APPE~~NDIX A~~

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ABSTRACT

The small body pressure transducers were used in both fixed-wing and rotary-wing scale models to measure dynamic and static pressures. These models were then tested under controlled wind tunnel conditions and the transducer signals recorded for either on- or off-line analyses.

One experiment using the small body pressure transducers was conducted in the American Aeromechanics Wind Tunnel (7 × 10 #2, NASA Ames, Moffett Field) in order to compare different geometrically shaped rotary-wing airfoil sections under dynamic stall conditions. An additional application for the small body pressure transducer was a series of tests conducted in both the French Tunnel, Saclay, France (CEPRA 19) and the Dutch-German Amsterdam, The Netherlands (DNW) wind tunnel. During the foreign tests, data were obtained on helicopter rotor noise generated by blade pressure disturbances due to helicopter blade-vortex interaction. Both the acoustic signature and the blade pressure transducer outputs were recorded simultaneously. In all of these experiments, special purpose electronic and mechanical hardware for the small body pressure transducers was developed.

INTRODUCTION

The need for determining the pressure distribution on aerodynamic shapes both in wind tunnel and in full-scale flight tests has brought about a steady evolution in both the mechanical design and the electrical properties of the pressure transducer. Twenty-five to thirty years ago, the majority of wind tunnel pressure surveys were for static measurement only. These measurements were taken with liquid manometers that, for the most part, were either read manually or photographed for later analysis. In the early 1950s, a project was undertaken at the NACA Ames Aeronautical Laboratory and other centers around the country to develop and apply a technique whereby dynamic pressures could be measured. Previously, these unsteady pressures could not be recorded on liquid manometers. The resulting efforts at Ames developed a series of pressure transducers starting with a single active leg, going to a half bridge, and then to a full bridge in the form of a "bud" rosette gauge. The full-bridge transducers were powered by the CEC 20KC carrier equipment, and the output was recorded on Consolidated Electrodynamics Corporation (CEC) oscillographs. These pressure transducers were 1/4 in. diameter by 1/8 in.

deep with the strain gauge bonded to the interface of a stainless steel diaphragm. This diaphragm was then spot-welded to the case body. In the case of either the single leg or the one-half bridge transducer, the bridge completion resistors were mounted near the transducer on a steel block; if precision resistors were used, they were located on the inner surface of the model. The desire was to keep temperature effects to a minimum.

In the 1950s, a big step forward in transducer development came with the advent of the piezoresistive-semiconductor gauges that opened a whole new field for development. Such representative entrepreneurs as Micro-Systems and Kulite-Bytrex and then Schaevitz-Bytrex and Kulite in the 1960s led the way in the development of this new technology. They were able to supply the testing market with a valuable new tool which had great potential. The current transducer state of the art offers many advantages including small size, high output, and both static and dynamic response. The major objective of this paper is to report two recent small body pressure transducer applications and some of the hardware developed for improved calibration and monitoring techniques.

EXPERIMENTAL RESULTS

A. Oscillating Airfoil Studies

An oscillating airfoil test using the small body pressure transducer was conducted in the 7- by 10-foot wind tunnel at NASA Ames Research Center (ARC). This test used the Kulite model YQCH-250-1 and YQCH-093-15D pressure transducers (Fig. 1). The purpose of the test was to determine the dynamic stall characteristics of the advanced rotary-wing airfoil sections.[1] Twenty-six Kulite transducers were distributed over the upper and lower surfaces of eight different geometrically shaped airfoil sections (Figs. 2 and 3). These transducers were differential in type and referenced to tunnel total pressure. Each transducer was powered by 5 VDC and the output balanced for zero voltage whenever the differential pressure was known to be zero. The signal was then filtered and gained for recording on an Ampex 32 channel analog magnetic recorder (Fig. 4).

Transducer calibrations were performed at 8- to 10-hr intervals. A set of starting zeroes was taken after tunnel warmup and again after each run (20 min). This procedure was to maintain a good DC zero reference level for measuring both steady and unsteady loads on the airfoil sections. Specifically, the calibration process made use of the pressure stepping ability of a Scanivalve (model SGM), a commutator, and a step-drive system (Fig. 5, Appendix A). The adaption of the Scanivalve allowed the rapid stepping of a multilevel pressure source without disconnecting any tubing, and then returned the transducers back to an operating reference pressure (P_T). Replacing the normal transducer in the Scanivalve with a dummy plug allowed six preset pressures to be ported out to a manifold which connected the reference side of all the

small body transducers. The pressure regulators were used to establish a nominal pressure value for each step. The absolute value of each step pressure was measured by means of the Parascientific Model 600 pressure computer, and with a quartz reference transducer connected in the pressure line between the Scanivalve and the model reference manifold. Of particular note was the outstanding durability of the small body transducers used in this test. The duration of tunnel occupancy for the model and the transducers was slightly over 1 yr. Following an initial shakedown run, during which several units were replaced, there were no further transducer failures during this period. (These initial failures during the shakedown were due to broken wires and occurred at the time of installation.)

An outstanding piece of electronics hardware that was developed for the oscillating airfoil program is the on-line pressure profile monitor (Fig. 6, Appendix A). It was designed and built by Don Humphry of the Electronic Development Branch, ARC. This instrument allows the operator to visually monitor any 10 pressure transducers at one time, for either the upper or lower surface of the model (Fig. 2). The resulting data are presented on a CRT of any standard laboratory oscilloscope. The display is calibrated for psi along the y-axis and for x/c transducer location along the x-axis. Ten pressure transducers could be selected and displayed as a continuous line representing the pressure profile at a predetermined angle of attack of the model in the air system. The airfoil motions are generated by means of a mechanical device (Fig. 7) and are controlled in both amplitude and rate of oscillation.

Helicopter Blade-Vortex Interaction Study

Two sequential wind tunnel tests were conducted using the small body pressure transducers, model XCQ-63-093-25A and the model XCQ-65-096-10D (Fig. 8). The purpose of these tests was to study the scaling of helicopter blade-vortex interaction. The first test was conducted in CEPRA 19 anechoic wind tunnel configured with a 3-m open test section.[2] (CEPRA 19 is located south of Paris, near Saclay, France.) The second wind tunnel test was conducted in the new DNW wind tunnel, an aerodynamic and aeroacoustic low speed facility.[3] (The DNW is a German-Dutch cooperative project, located northeast of Amsterdam, The Netherlands.)

The rotor stand (Fig. 9), which was used to mount and run the rotor blades, was designed and built for the U.S. Army Aeromechanics Laboratory, ARC.[4] Also, two instrumented pressure blades for these tests (Figs. 10 and 11) were fabricated and instrumented with small body transducers at ARC.

A method was devised to select and to precalibrate all of the pressure transducers that were installed into the two rotor blades. This preinstallation calibration determined the transducer response to pressure in units of volts per psi, and the sensitivity to both temperature and time (see Appendix B for typical calibration format). With few exceptions it was found that the transducers were well matched and the

assignment of position of transducers on the rotor blade presented no problem. After the transducers were installed on the rotor blade and the blade then mounted on the rotor stand, an end-to-end calibration technique was devised whereby all absolute transducers could be calibrated at one time. This procedure allowed setting excitation voltages to produce a common-slope calibration for all transducers, both absolute and differential, thereby giving on-line quantitative monitoring of blade pressure responses. This end-to-end calibration device consisted of a clear plastic cylinder which could be sealed at both ends. The cylinder is shown enclosing the blade instrumented with absolute pressure transducers in Fig. 12. This cuffing technique for calibration had been tried in the past but with little success. Appropriate attention to blade construction, transducer installation, and calibrator design resulted in leak-free pressure calibrations, making it simple to simultaneously and accurately calibrate many transducers.

The sealed calibration cylinder was pneumatically connected to a volumetric pressure piston and monitored by a Parascientific Model 600 pressure computer, using a 15 psid quartz transducer as a reference (Fig. 13). A series of 0.5 psi reducing pressure steps was generated and the transducer outputs were recorded on a 32-channel Ampex tape recorder. The transducer signals were gained to match the recorder level of 1 V rms for the largest Δp step of approximately 4 psid The recordings were made at 30 ips and FM wide Band 1, which allowed a playback band pass of 20K Hz.

The end-to-end calibration for the second blade, which was instrumented with differential pressure transducers, presented a more complex problem as the sealed volume calibrator technique inherently would not work. The problem for the differential transducers occurred because there was no practical way to seal one side of the transducer. Many techniques and materials including various types of tape were attempted but always induced zero shifts that could not be calibrated. All tapes that were tested resulted in deformable cavities under pressure at the orifice opening and the transducer diaphragm never returned to original zero condition. Therefore, a transducer-by-transducer calibration was performed instead. A corollary technique for simultaneous calibration of blade-installed differential (both sides open) small body transducers is still needed.

The transfer of data from the rotating blade system was made possible by means of a 156-channel, high speed, Poly-Scientific slip-ring. An important requirement in the use of this slip-ring was to maintain a very clean brush-to-ring environment. Both the CEPRA 19 and the DNW wind tunnel tests were conducted using the same slip-ring assembly and without any channel failures. The slip ring used during these tests proved to be a well-manufactured unit and was maintained by flushing the slip-ring brush areas on a regular basis. Specifically, after every 20 hr of use, a mixture of one part synthetic oil (Exxon 2380) and nine parts freon was forced into the contact area and allowed to drain.

CONCLUSION

The small body pressure transducer has proven to be a very useful tool in the acquiring of both static and dynamic data. With the advent of the piezoresistive-semiconductor gauge, the state of the art in pressure measurements has increased in such areas as pressure range, sensitivity, and in the reduction of physical size of transducers. These improved properties have allowed the test engineer to more reliably measure and monitor the physical changes taking place in the test environment. In addition, the interfacing instrumentation has also kept pace with this change and has enabled the engineer to monitor, to record and to accurately calibrate, the transducer prior to and during its application in a test situation.

REFERENCES

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[2]Schmitz, F. H., Boxwell, D. A., Lewy, S., and Dahan, C., "A Note on the General Scaling of Helicopter Blade-Vortex Interaction Noise," Paper presented at the 38th Annual Forum of the American Helicopter Society, Anaheim, California, May 1982.

[3]Seidel, M. and Maarsingh, R. A., "Test Capabilities of the German-Dutch Wind Tunnel DNW for Rotor, Helicopter and V/STOL Aircraft," Paper presented at the 5th European Rotorcraft and Powered Lift Aircraft Forum, Paper No. 17, Sept. 1979, Amsterdam, The Netherlands.

[4]Laub, G. H., "A Unique Drive System for Testing Model Scale Rotors," Article in VERTIFLITE, Vol. 29, No. 2, Jan./Feb. 1983, pp. 50-51.

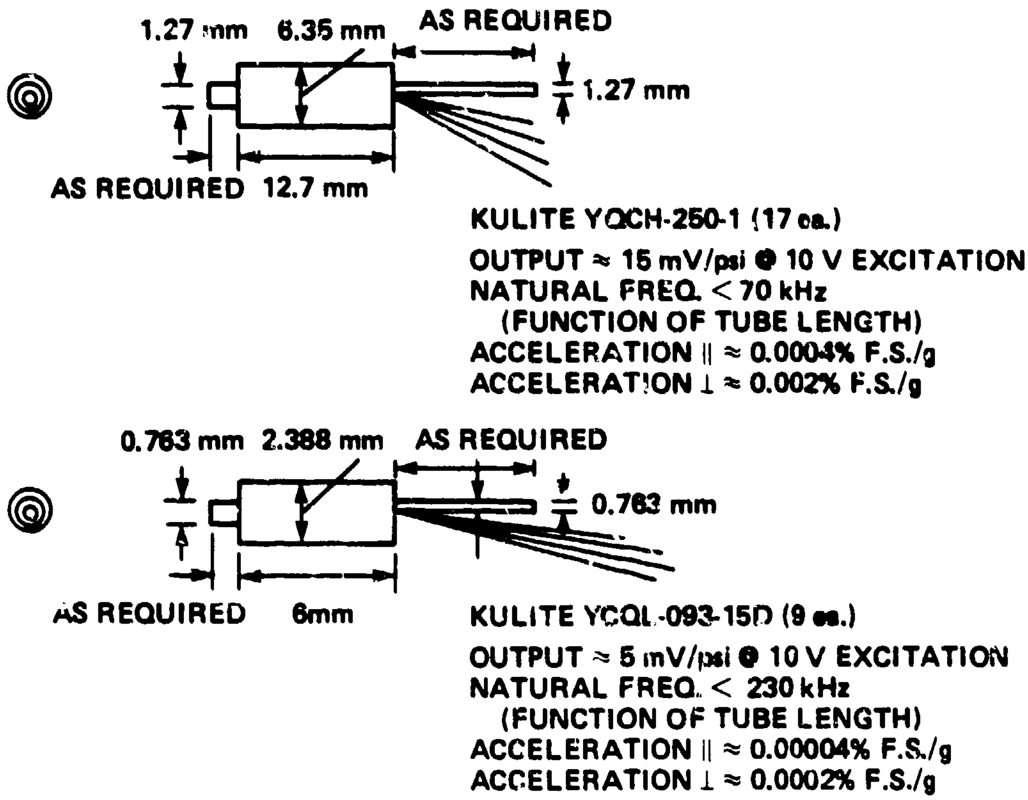
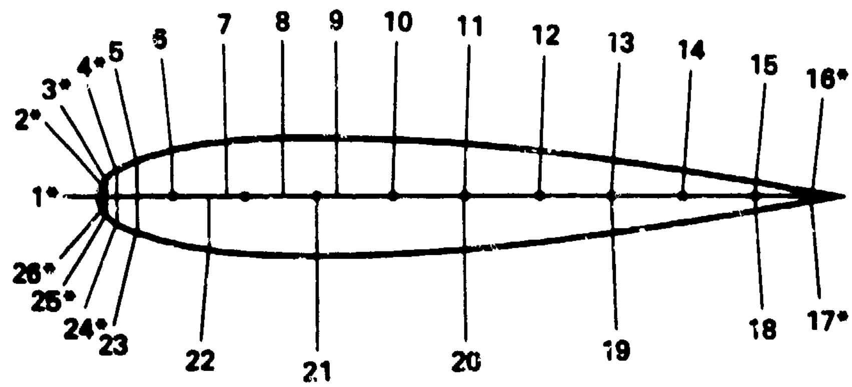


Figure 1 Pressure transducers for oscillating air foil



#	X/C	#	X/C	#	X/C	#	X/C
1	0.000	8	0.250	15	0.900	21	0.300
2	0.005	9	0.325	16	0.980	22	0.150
3	0.010	10	0.400	17	0.980	23	0.050
4	0.025	11	0.500	18	0.900	24	0.025
5	0.050	12	0.600	19	0.700	25	0.010
6	0.100	13	0.700	20	0.500	26	0.005
7	0.175	14	0.800				

TRANSDUCERS USED YQCH-250-1
AND YCQL-093-15D*

Figure 2 Upper and lower surface pressure transducer locations for all eight stall models

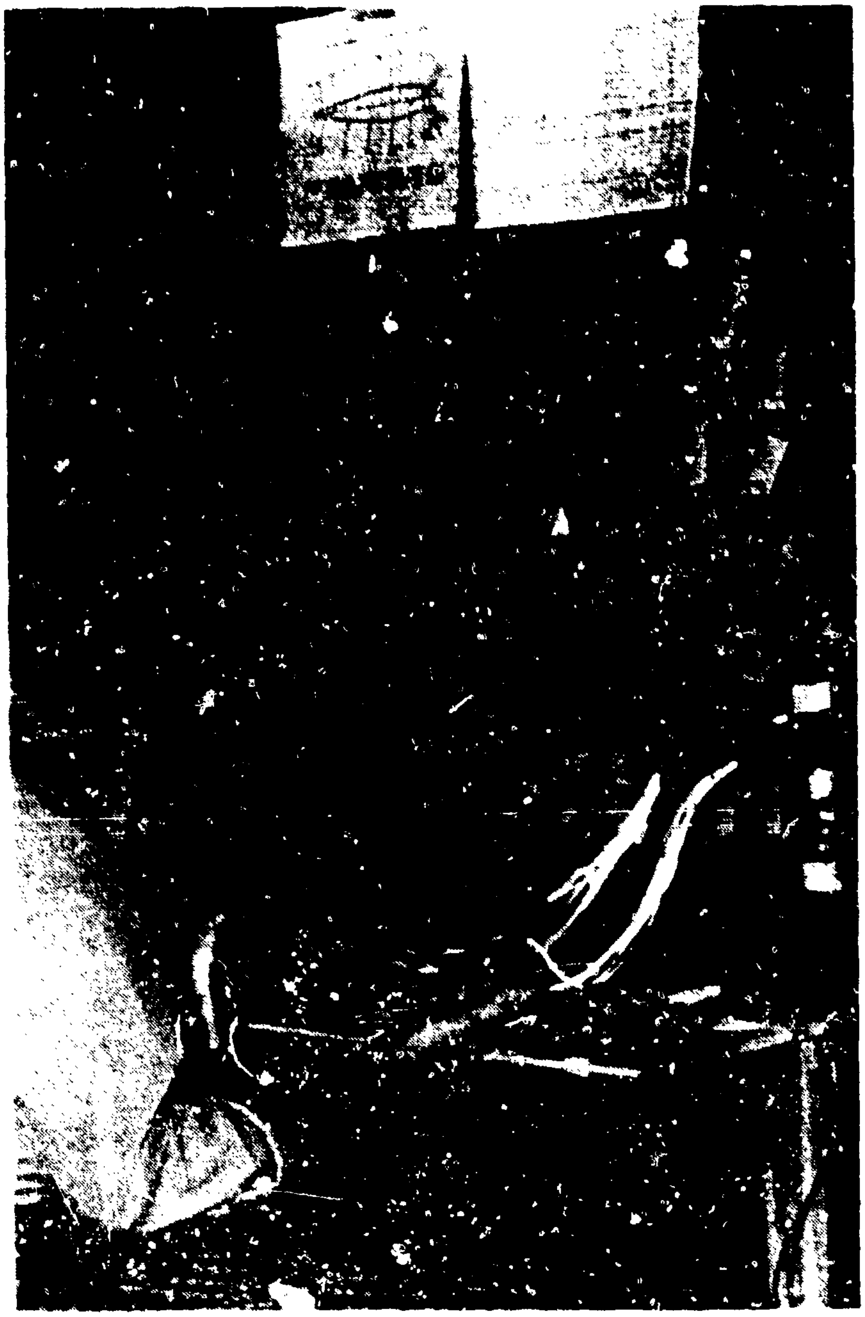


Figure 3 Installing transducers in the oscillating airfoil

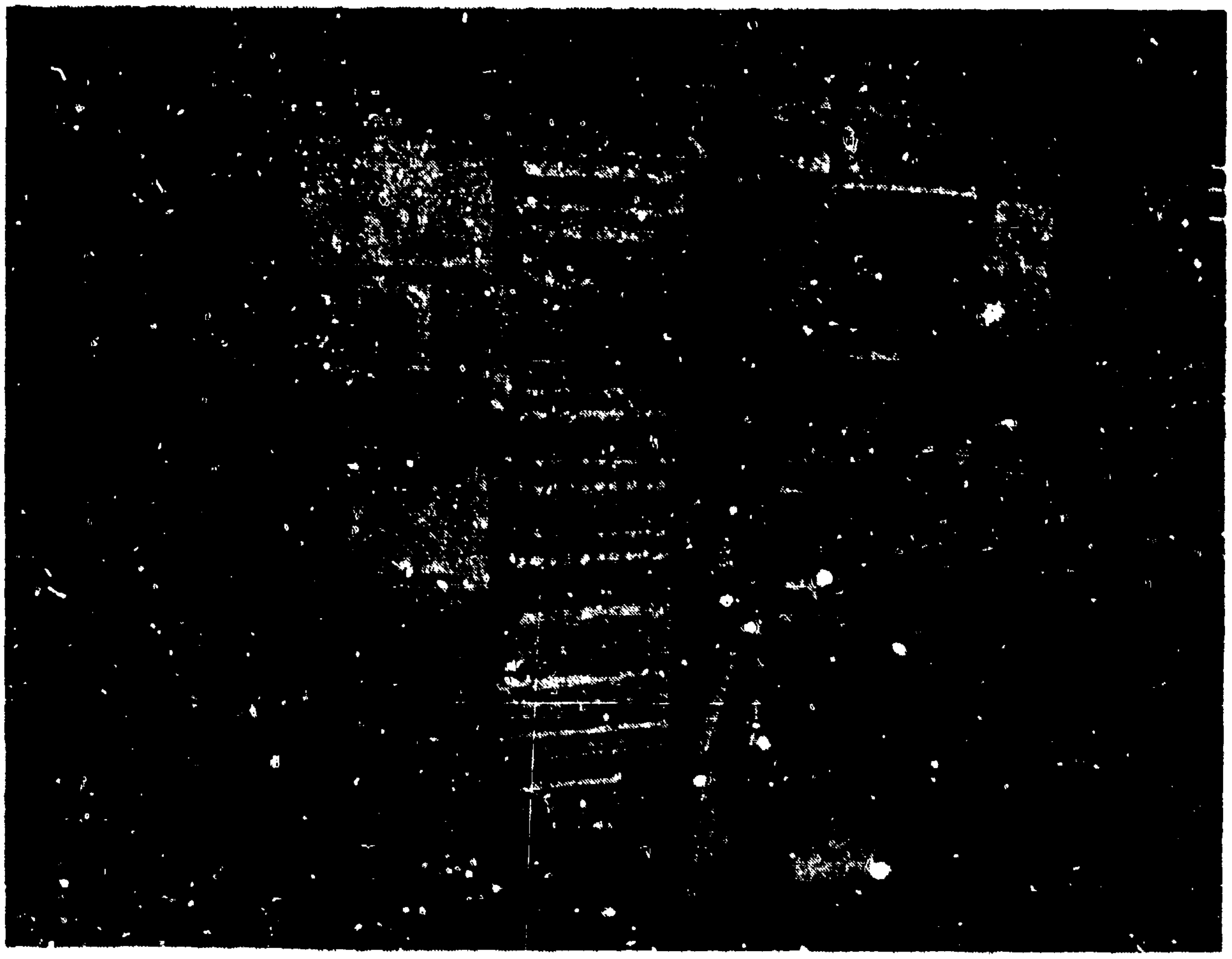


Figure 4 Electronics involved in monitoring and recording data signals

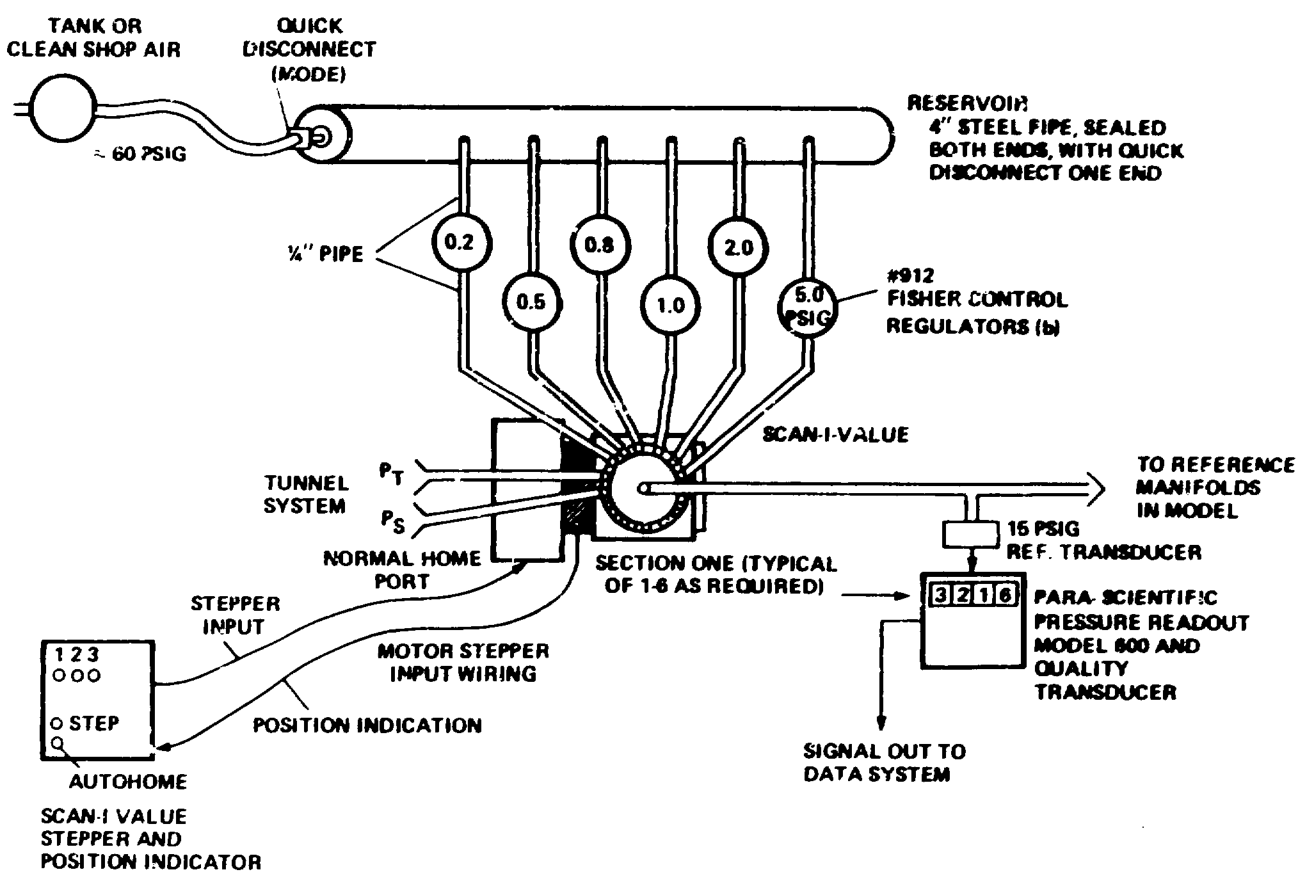


Figure 5 Pressure calibration stepping device

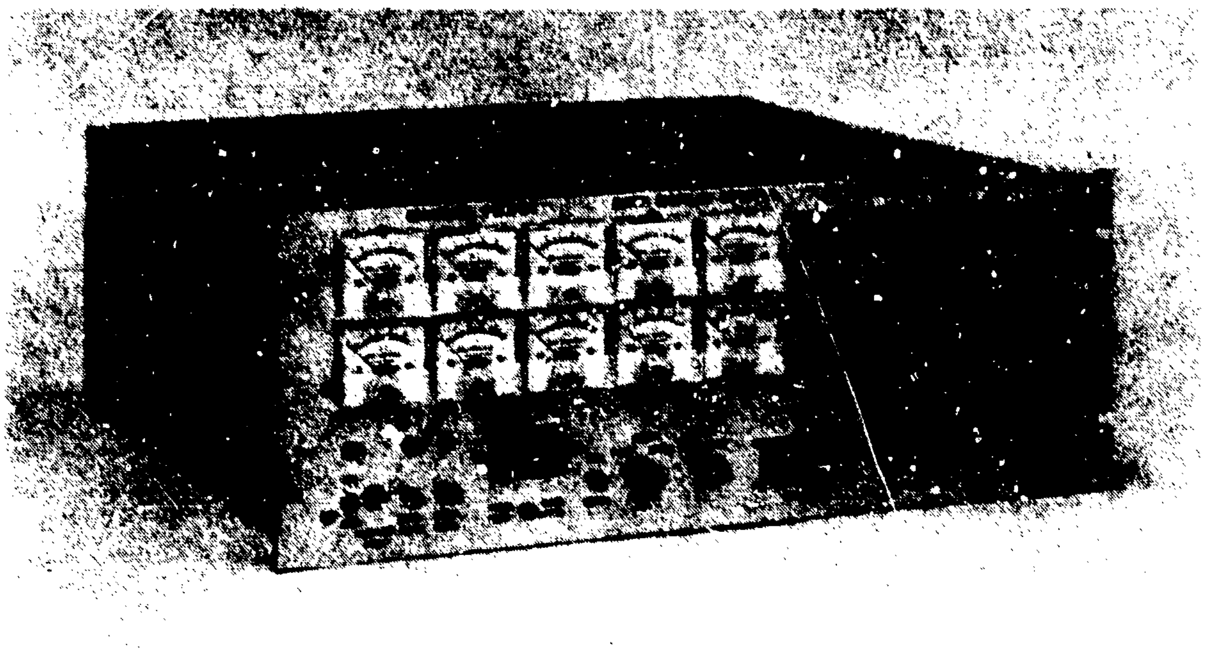


Figure 6   On-line pressure profile monitor

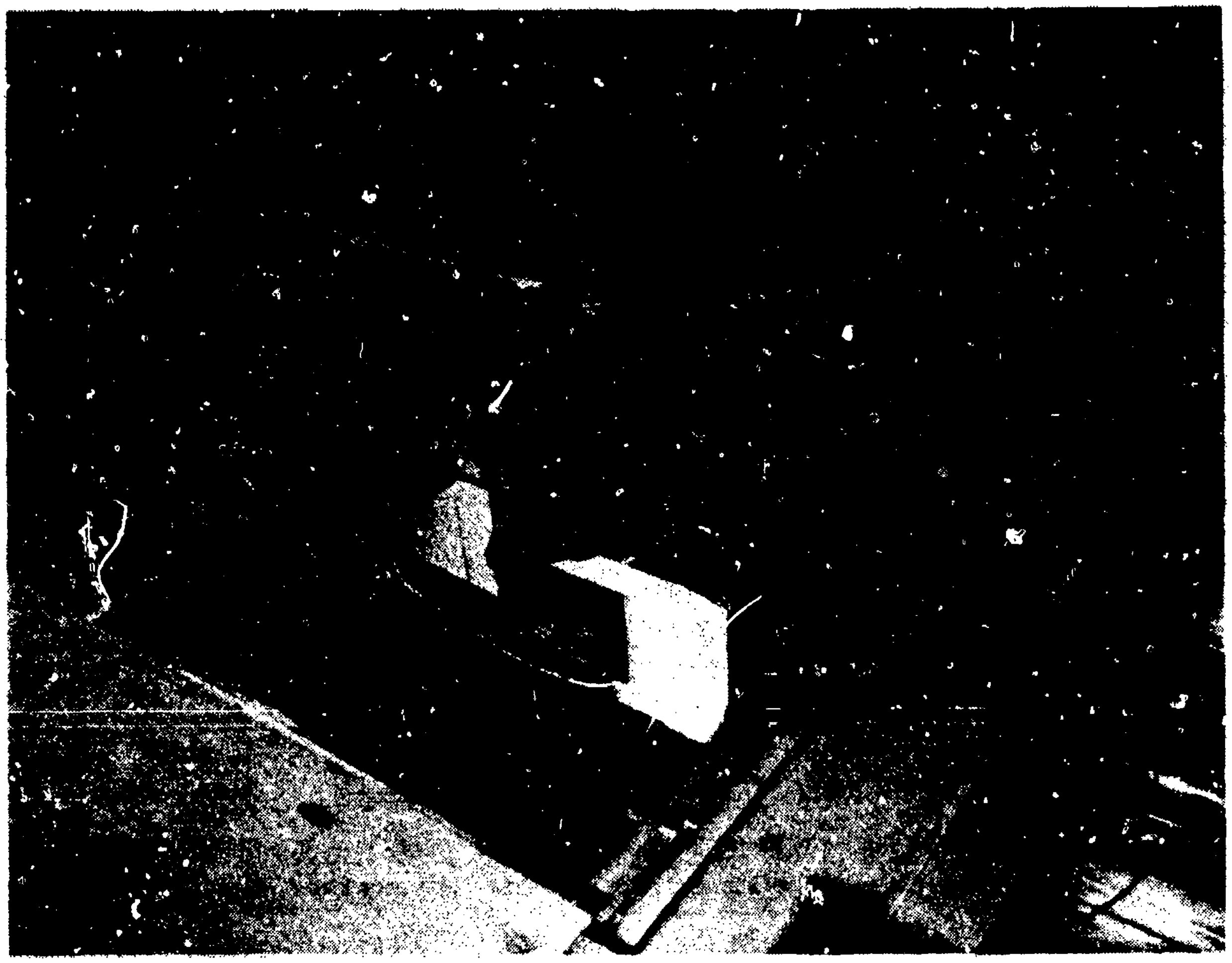


Figure 7 View of mechanical device to drive oscillating airfoil

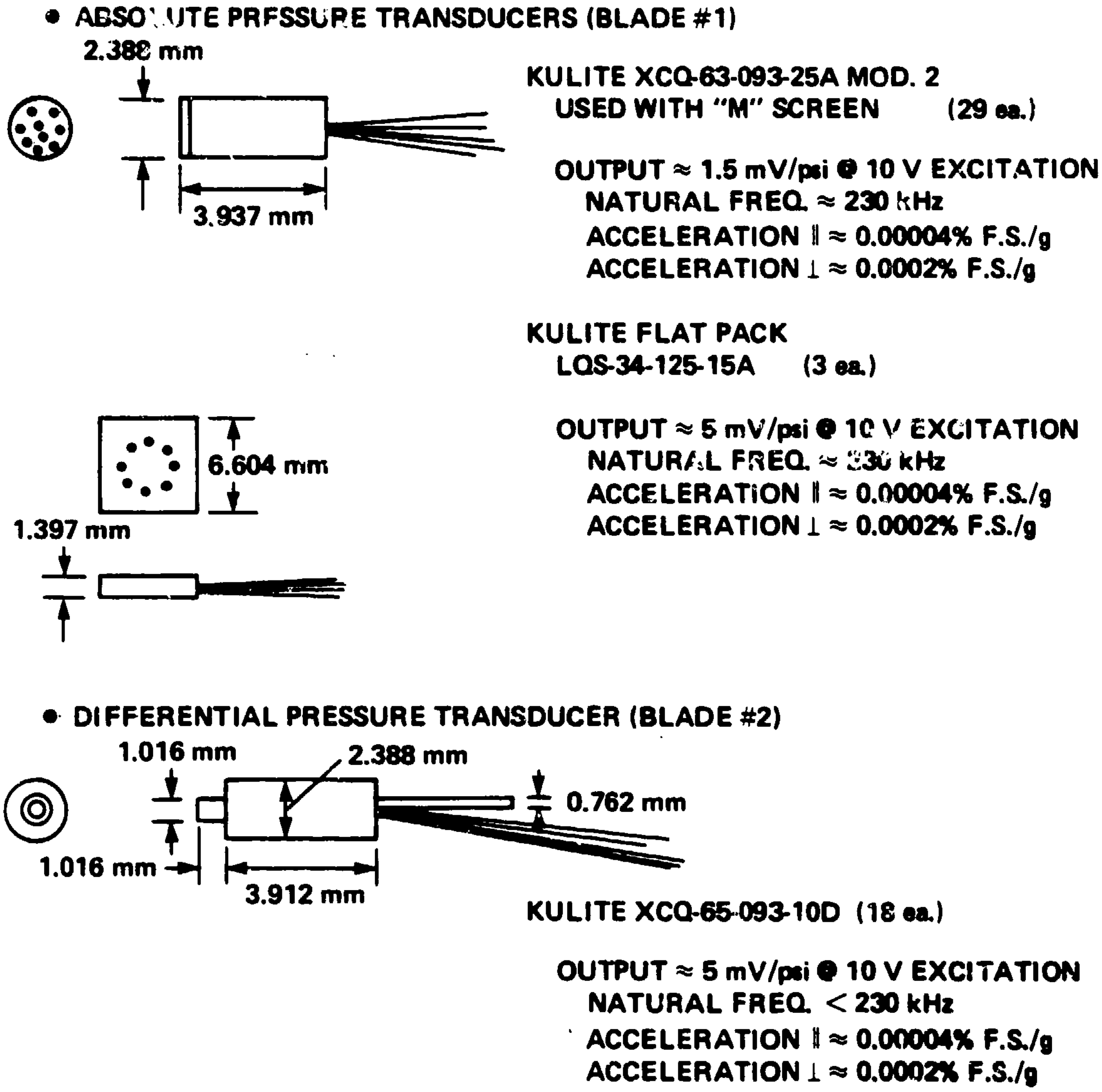


Figure 8 Pressure transducers for small body model rotor blades

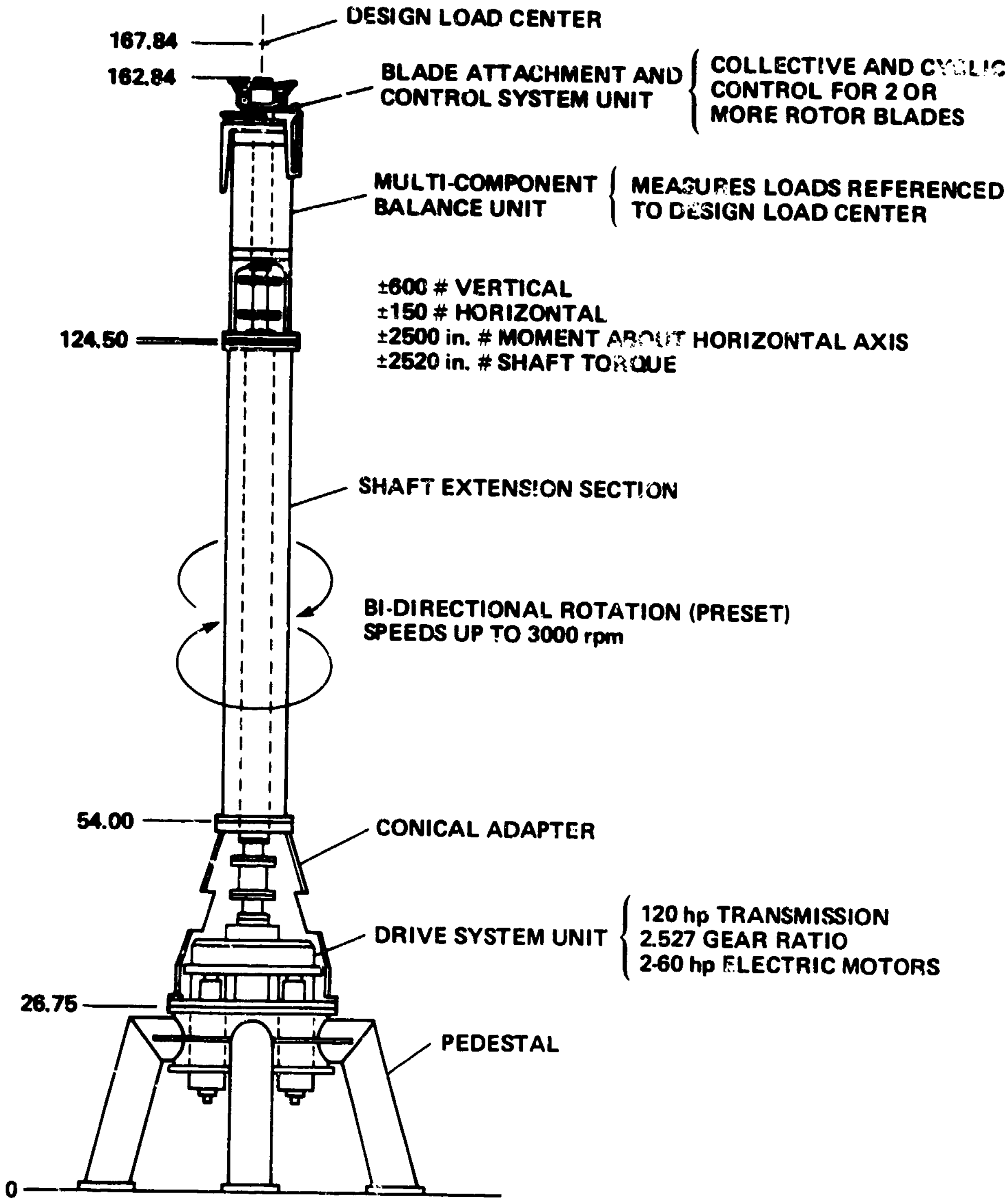


Figure 9 Operational characteristics rotary wing test stand

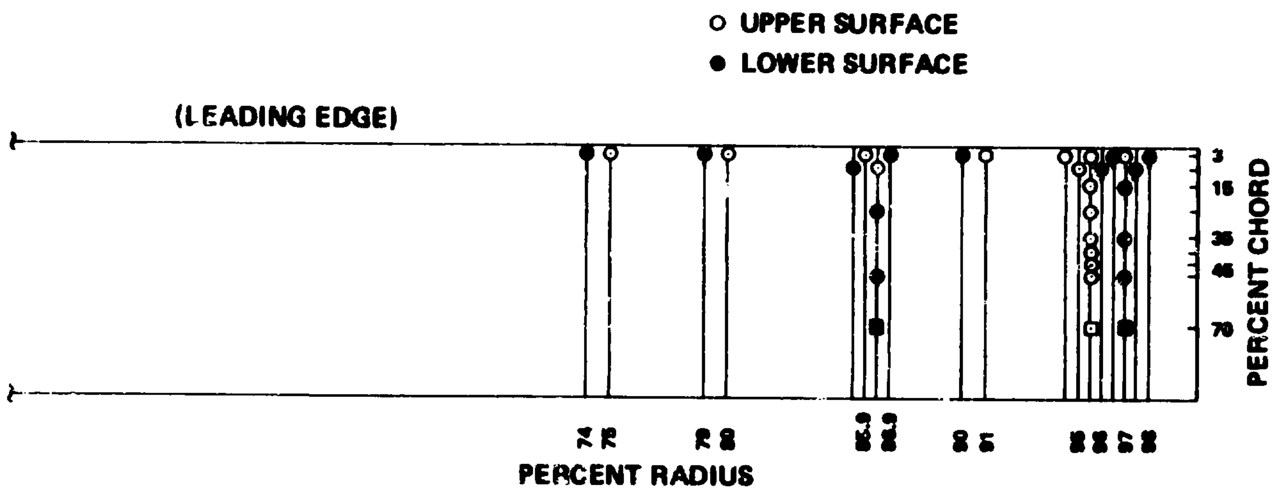


Figure 10 Scale model AH-1/OLS rotor blade absolute pressure transducer locations

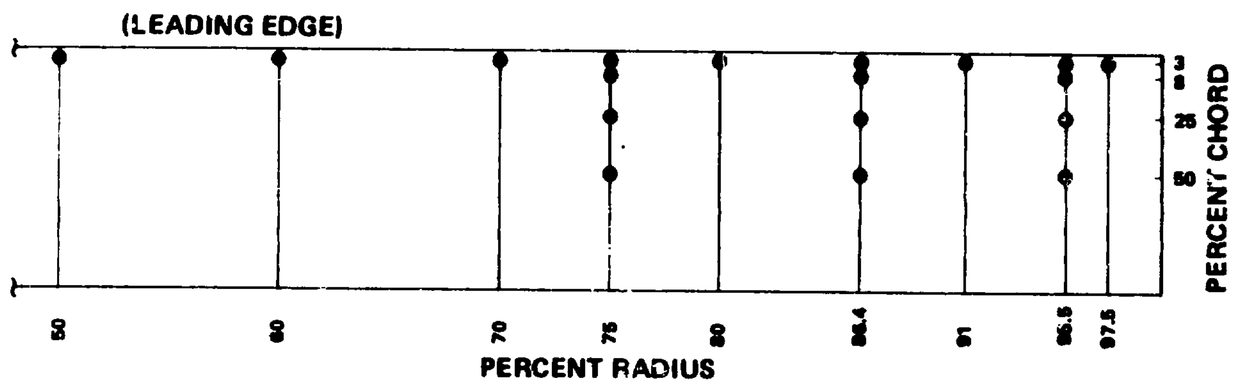


Figure 11 Scale model AH-1/OLS rotor blade differential pressure transducer locations

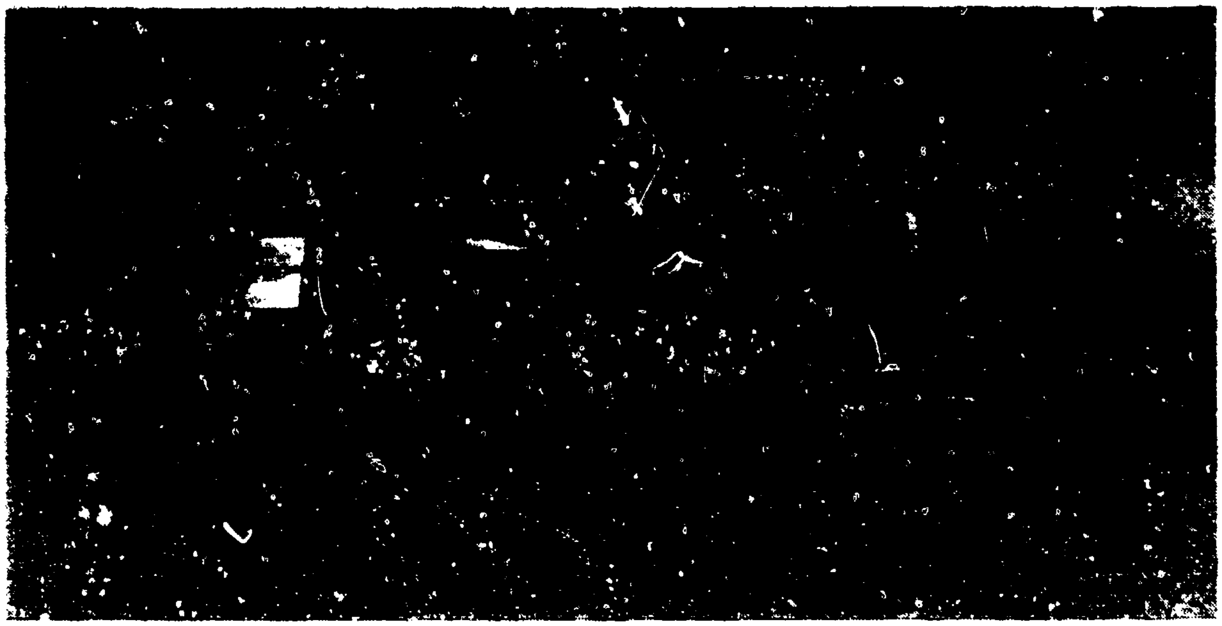


Figure 12 Pressure transducer calibration sleeve and the rotor blades

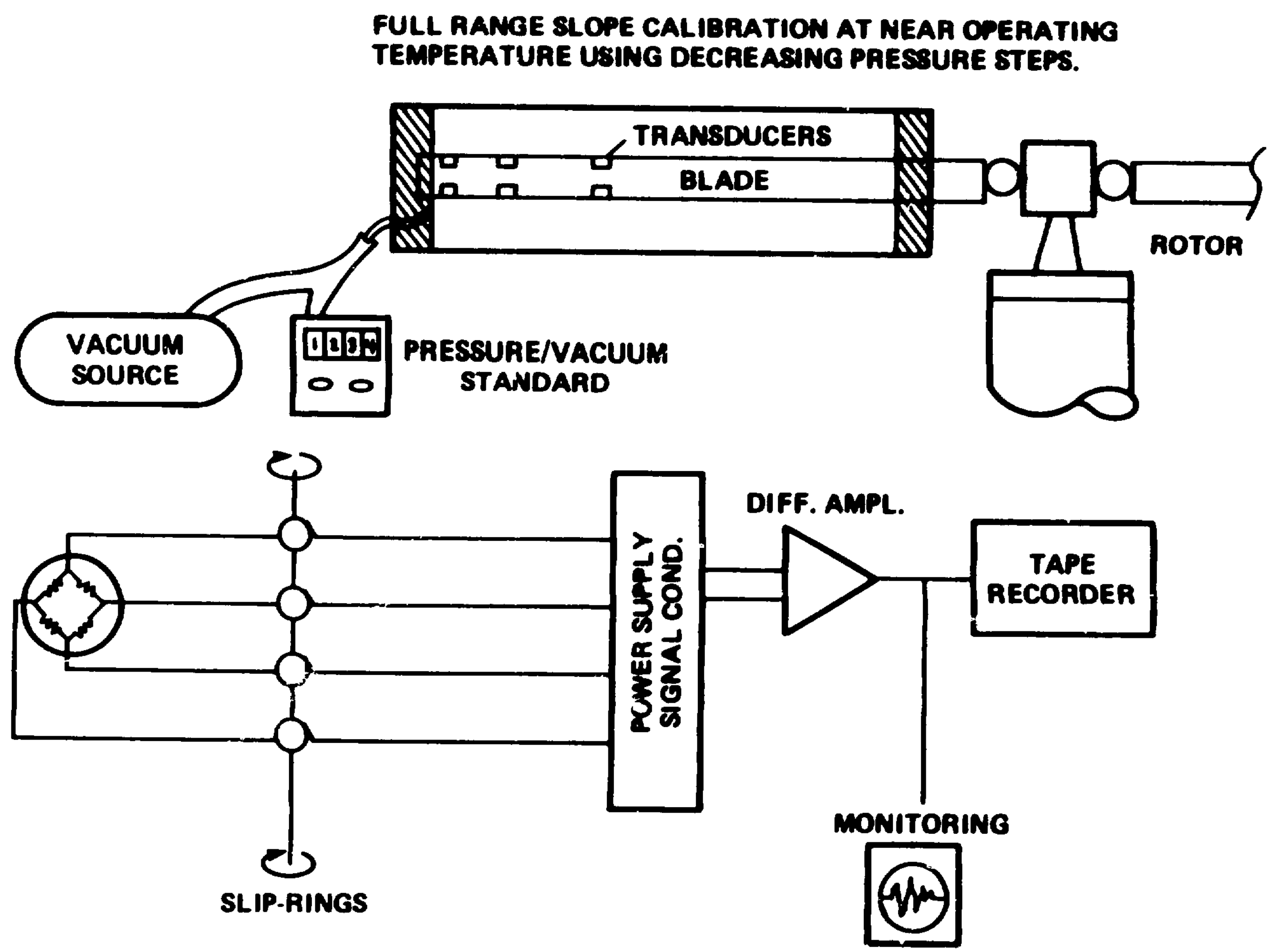


Figure 13 Post installation transducer calibration and recording

APPENDIX A

DATA DISPLAY SYSTEM

Donald E. Humphry

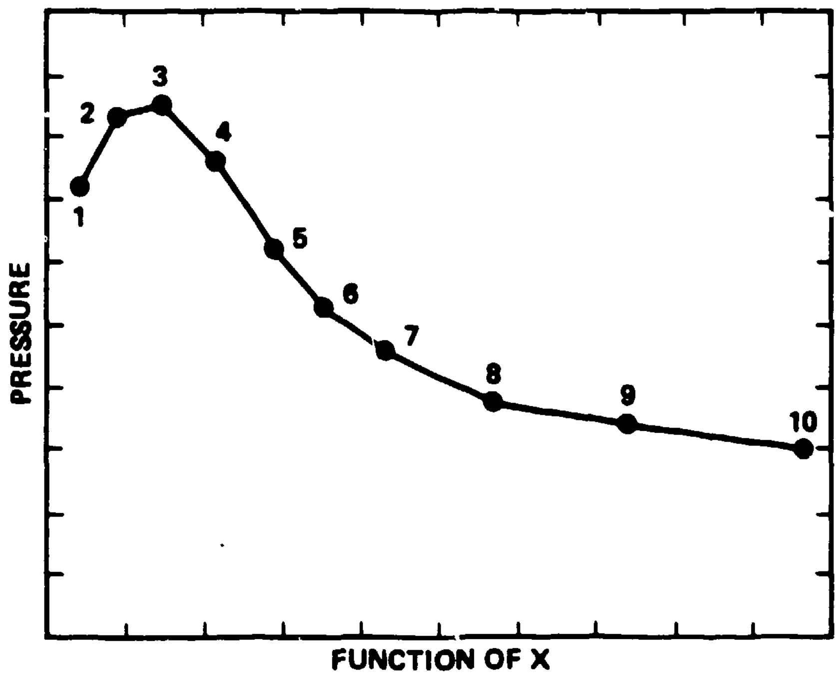
A 10-channel data-display system has been developed to illustrate a pressure profile of a moving airfoil during wind tunnel testing. The inputs to the system are the 10 analog signals from the pressure transducers and a synchronizing pulse that corresponds to the zero rotational angular position of the airfoil. This pressure profile is presented on an oscilloscope. A typical display is shown in Fig. 1. Each brightened point or dot on the trace indicates the pressure reading at that particular location with the vertical distance being the pressure, and the horizontal distance between dots being proportional to the horizontal spacing of the pressure transducers on the airfoil. This pressure profile is also for a selected rotational angle of the rotating or oscillating airfoil. The 10 simultaneous pressure readings are taken at the selected rotational angle. Thus the display system acts like a strobe, with the pressure profile being taken at any selected angular position of the airfoil.

Also displayed on the oscilloscope is a second trace, which shows the selected rotational angle of the airfoil at which the pressure readings are occurring as shown on the pressure profile. This is indicated by the position of a brightened point or dot on this trace, which corresponds to the selected rotational angle.

The horizontal position of each of the 10 channels on the pressure profile trace is adjustable, so that they correspond to the actual physical location of each of the pressure transducers on the airfoil.

The rotational angle of the airfoil at which the pressure reading is recorded is adjustable from 0 to 360°. For instance, to take a pressure reading at a rotational angle of 45°, select a 45° by means of a front panel switch and then each time the airfoil passed through 45°, a pressure reading would be taken at all 10 channels and displayed on the scope as a pressure profile. The system can also be programmed to scan through different angular readings at varying rates, which can be set by means of some front panel switches.

This system has also proven useful in the calibration of the pressure transducers since all 10 pressures can be observed simultaneously and any variations between them are easily observed.



Appendix A - Figure 1. Typical display off the on-line pressure profile monitor

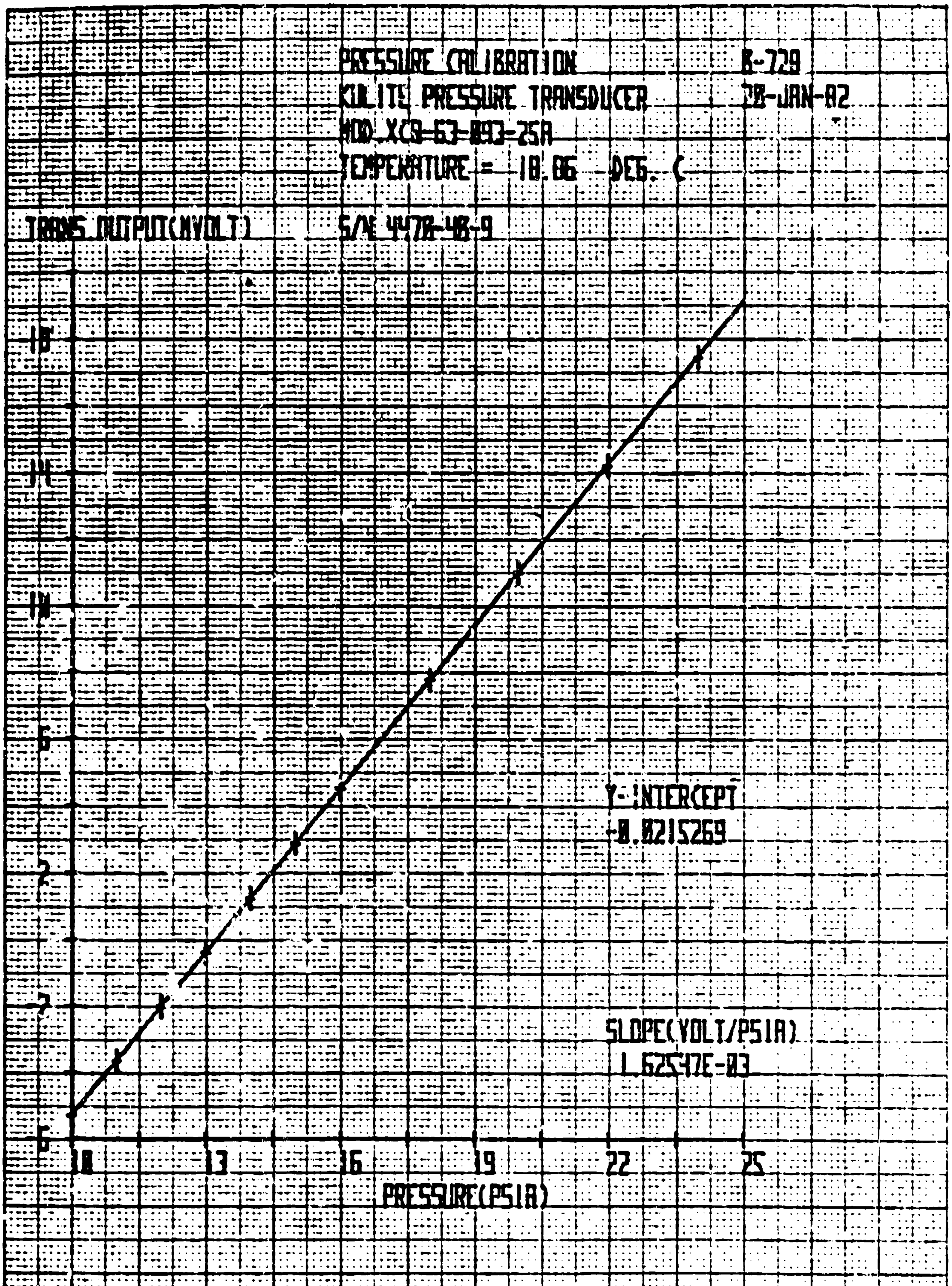
APPENDIX B

PRESSURE CALIBRATION
KULITE PRESSURE TRANSDUCER — B-728
MOD.XCQ-63-093-25A — 20-JAN-82
S/N 4470-4B-9
CALIB. RANGE : 10 TO 24.0 PSIA
EXCITATION= 10.00 VDC
TEMPERATURE = 18.857 DEG. C

.#	PRESS(PSIA)	OUTPUT VOLT.	CALC.PRESS	DEV.(PSIA)
1	10.002	-0.005293	9.9872	0.0148
2	11.000	-0.003652	10.9966	0.0036
3	12.000	-0.002018	12.0022	-0.0018
4	13.000	-0.000389	13.0044	-0.0043
5	14.001	0.001238	14.0053	-0.0048
6	15.000	0.002868	15.0077	-0.0074
7	16.001	0.004499	16.0112	-0.0100
8	18.000	0.007752	18.0123	-0.0124
9	20.001	0.010995	20.0074	-0.0064
10	22.001	0.014220	21.9915	0.0091
11	24.001	0.017450	23.9789	0.0218
12	22.001	0.014220	21.9915	0.0092
13	20.001	0.010993	20.0067	-0.0060
14	18.001	0.007750	18.0110	-0.0102
15	16.000	0.004496	16.0093	-0.0089
16	15.001	0.002865	15.0062	-0.0053
17	14.001	0.001236	14.0040	-0.0030
[illegible]	13.001	-0.000392	13.0023	-0.0016
[illegible]	12.001	-0.002021	12.0003	0.0003
20	11.001	-0.003655	10.9948	0.0060
21	10.001	-0.005299	9.9833	0.0174

INTERCEPT	SLOPE(VOLT/PSIA)	R↑2	STD.DEV.(PSIA)
.152690E-02	1.625470E-03	0.999994	0.009661

NOTE : CALC. PRESS = (OUTPUT VOLTAGE--0.0215269)/ 1.62547E-03

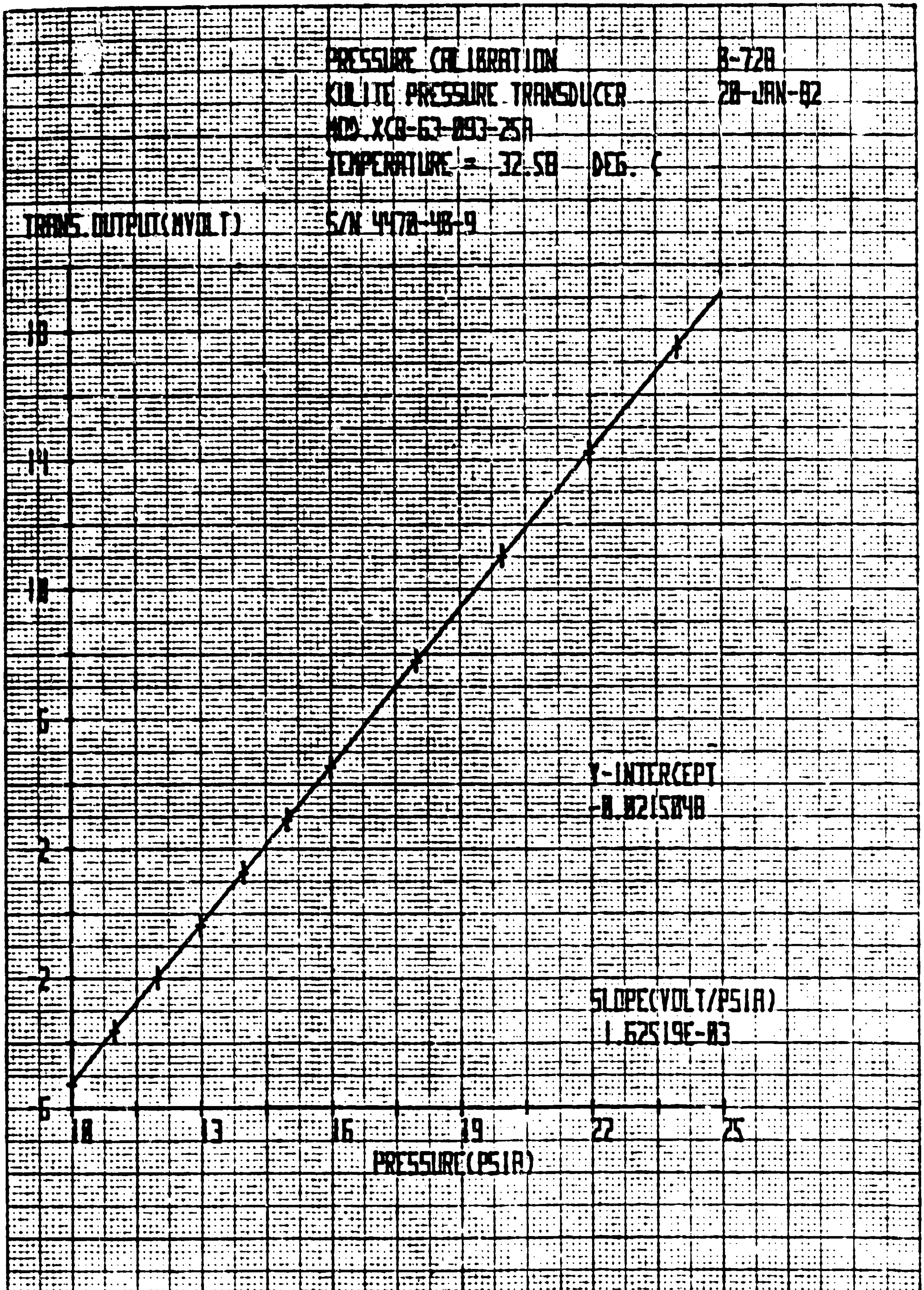

PRESSURE CALIBRATION
B-728
KULITE PRESSURE TRANSDUCER
28-JAN-82
MOD XCQ-63-093-25A
TEMPERATURE = 18.86 DEG. C
TRANS OUTPUT(MVOLT)
S/N 4478-48-9
Y-INTERCEPT
-0.0215269
SLOPE(VOLT/PSIA)
1.62547E-03
PRESSURE(PSIA)
10
13
16
19
22
25

PRESSURE CALIBRATION
KULITE PRESSURE TRANSDUCER — 8-728
MOD.XCQ-63-093-25A — 20-JAN-82
S/N 4470-4B-9
CALIB. RANGE : 10 TO 24.0 PSIA
EXCITATION= 10.00 VDC
TEMPERATURE = 32.577 DEG. C

.#	PRESS(PSIA)	OUTPUT VOLT.	CALC.PRESS	DEV.(PSIA)
1	10.001	-0.005276	9.9855	0.0154
2	11.000	-0.003634	10.9959	0.0044
3	12.001	-0.002001	12.0009	-0.0004
4	13.001	-0.000371	13.0039	-0.0031
5	14.001	0.001256	14.0052	-0.0047
6	15.001	0.002885	15.0070	-0.0064
7	16.001	0.004513	16.0093	-0.0087
8	18.001	0.007767	18.0113	-0.0105
9	20.000	0.011010	20.0065	-0.0061
10	22.001	0.014235	21.9911	0.0097
11	24.001	0.017467	23.9795	0.0212
12	22.001	0.014236	21.9918	0.0089
13	20.001	0.011011	20.0073	-0.0068
14	18.001	0.007768	18.0120	-0.0114
15	16.000	0.004514	16.0099	-0.0096
16	15.001	0.002885	15.0072	-0.0066
17	14.000	0.001256	14.0049	-0.0047
18	13.001	-0.000371	13.0040	-0.0034
	12.001	-0.002001	12.0010	-0.0004
20	11.000	-0.003637	10.9946	0.0058
21	10.000	-0.005279	9.9841	0.0163

INTERCEPT	SLOPE(VOLT/PSIA)	R↑2	STD.DEV.(PSIA)
.150480E-02	1.625190E-03	0.999994	0.009531

NOTE : CALC. PRESS = (OUTPUT VOLTAGE--0.0215048)/ 1.62519E-03


PRESSURE CALIBRATION
B-72A
KULITE PRESSURE TRANSDUCER
20-JAN-82
MOD. XCQ-63-093-25A
TEMPERATURE = 32.58 DEG. C
TRANS. OUTPUT(MVOLT)
S/N 4470-48-9
18
14
10
6
2
2
6
10
13
16
19
22
25
PRESSURE(PSIA)
Y-INTERCEPT
-0.0215048
SLOPE(VOLT/PSIA)
1.62519E-03

VOLTAGE DRIFT TEST
KULITE PRESSURE TRANSDUCER
MOD.XCQ-63-093-25A
S/N 4470-48-9
MEAN PRESSURE - 14.518 PSIA
EXCITATION= 10.00 VDC

A-723
20-JAN-82

POINT #	TRANS.OUTPUT	DRIFT	TEMP. C	TIME(MIN)
1	0.002092	0.000000	32.033	0.000
2	0.002092	0.000001	32.003	0.750
3	0.002090	-0.000001	31.902	1.500
4	0.002090	-0.000002	31.923	2.167
5	0.002091	-0.000001	31.843	3.000
6	0.002090	-0.000002	31.785	3.750
7	0.002091	-0.000001	31.639	4.500
8	0.002090	-0.000002	31.624	5.250
9	0.002090	-0.000002	31.536	6.000
10	0.002088	-0.000004	31.971	6.750
11	0.002088	-0.000004	31.461	7.500
12	0.002088	-0.000004	31.505	8.167
13	0.002086	-0.000006	31.470	9.000
14	0.002086	-0.000006	31.462	9.750
15	0.002085	-0.000006	31.518	10.500
16	0.002085	-0.000007	31.502	11.250
17	0.002086	-0.000006	31.537	12.000
18	0.002086	-0.000006	31.507	12.750
19	0.002087	-0.000005	31.517	13.500
20	0.002088	-0.000004	31.512	14.250
21	0.002087	-0.000004	31.597	15.000
22	0.002088	-0.000004	31.524	15.750
23	0.002087	-0.000005	31.553	16.500
24	0.002087	-0.000004	31.574	17.250
25	0.002087	-0.000005	31.575	18.000
26	0.002087	-0.000005	31.584	18.750
27	0.002087	-0.000005	31.535	19.500
28	0.002087	-0.000005	31.580	20.167
29	0.002087	-0.000005	31.576	21.000
30	0.002087	-0.000005	31.526	21.750
31	0.002087	-0.000005	31.468	22.500
32	0.002087	-0.000005	31.502	23.167
33	0.002086	-0.000005	31.483	24.000
34	0.002087	-0.000005	31.475	24.750
35	0.002087	-0.000005	31.544	25.500
36	0.002087	-0.000005	31.529	26.250
37	0.002087	-0.000004	31.591	27.000
38	0.002087	-0.000005	31.628	27.667
39	0.002087	-0.000005	31.536	28.500
40	0.002088	-0.000004	31.504	29.250

TEMPERATURE DRIFT TEST
KULITE PRESSURE TRANSDUCER A-728
MOD.XCQ-63-093-25A 20-JAN-82
S/N 4470-4B-9
MEAN PRESSURE - 14.523 PSIA
EXCITATION= 10.00 VDC

OINT #	TRANS.OUTPUT	DRIFT	TEMP. C	TIME(MIN)
1	0.002089	0.000000	31.503	0.000
2	0.002089	0.000000	31.073	1.000
3	0.002089	0.000000	27.724	2.000
4	0.002089	0.000000	25.361	3.000
5	0.002088	-0.000001	22.958	4.000
6	0.002086	-0.000002	22.192	5.000
7	0.002083	-0.000005	21.693	6.000
8	0.002080	-0.000009	21.407	7.000
9	0.002078	-0.000011	21.277	8.000
10	0.002075	-0.000014	20.889	9.000
11	0.002072	-0.000016	20.945	10.000
12	0.002069	-0.000019	20.795	11.000
13	0.002066	-0.000022	20.811	12.000
14	0.002067	-0.000022	20.733	13.000
15	0.002066	-0.000023	20.684	14.000
16	0.002064	-0.000024	20.261	15.000
17	0.002063	-0.000026	19.981	16.000
18	0.002061	-0.000028	19.839	17.000
19	0.002058	-0.000030	19.773	18.000
20	0.002058	-0.000031	19.739	19.000